

April 2017

Two Cosmic Coincidences for Minimal Standard Model with General Relativity

Paul H. Frampton^{(a)*} and Holger B. Nielsen^{(b)†}

^(a) *Department of Mathematics and Physics “Ennio de Giorgi”,
University of Salento, Lecce, Italy.*

^(b) *The Niels Bohr Institute, University of Copenhagen,
Blegdamsvej 17, 2100 Copenhagen, Denmark.*

Abstract

It is said that there are no accidents or coincidences in physics. Within the minimal standard model combined with general relativity we point out that there are three exceptionally-long lifetimes which are consistent with being equal, and hence that there are two unexplained coincidences.

*paul.h.frampton@gmail.com

†hbech@nbi.dk

1 Introduction

The time scales or lifetimes associated with particle phenomenology vary between those for strong interactions which may be as short as $\sim 10^{-24}$ seconds up to exceedingly slow radioactive double beta decay by weak interactions which has a measured lifetime up to $\sim 10^{21}$ years and some even slower undetected processes such as proton decay.

In classical general relativity no particular time scales stand out beyond the present age of the universe $\sim 10^{10}$ yr which itself has no truly fundamental significance. When we consider black holes of very high mass, however, as we shall discuss there do emerge lifetimes of an exceptionally long type.

Buried in the gauge field theories which successfully describe particle phenomenology there are curious non-perturbative effects, instantons, which give rise also to exceptional lifetimes discussed in this article.

A third type of unusual lifetime arises from the recently understood origin of particle masses via the Englert-Brout-Higgs mechanism because the measured values of the symmetry-breaking parameters reveal that the physical vacuum is metastable with just such a long lifetime.

All three of these unusual lifetimes are consistent with being equal or approximately so. This represents two coincidences between three lifetimes which with present knowledge appear unrelated.

2 Lifetimes

2.1 Primordial Black Holes

It has been speculated [1, 2] that the dark matter in the Milky Way halo, as well as elsewhere in the universe, is comprised of Primordial Black Holes (PBHs). In the local halo the preferred mass range is between 25 and 625 solar masses corresponding to microlensing events of stars in the Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC) with durations between 1 and 5 years.

Elsewhere in the universe there exist far more massive black holes, for example those at the cores of galaxies with masses up to at least several times $10^{10}M_{\odot}$ and we expect that these are likewise primordial.

The mathematics of hybrid inflation [3, 4] shows the possibility to make PBHs all the way up to $10^{17}M_{\odot}$ if we allow the formation to wait until the end of

the radiation era at cosmic time $t \sim 50ky$. We note that PBHs with mass $10^5 M_\odot$ are made at $t \sim 1s$ and thereafter the mass grows linear in time. It seems unlikely that such a PBH, with a mass far greater than the largest cluster - indeed one millionth of the total mass of the universe - really exists in our universe but it is conceivable on general grounds that $10^{14} M_\odot$ PBHs might exist.

Such a gigantic PBH might be unassociated with any cluster or supercluster, and instead might simply drift alone. It is a very interesting question whether there are limits on their existence and how such limits might be established.

The lifetime for decay of such a massive black hole is given by a well-known formula, *e.g.* [5],

$$\tau_{PBH} \simeq 10^{64} \left(\frac{M_{PBH}}{M_\odot} \right)^3 \text{ yr.} \quad (1)$$

Taking the largest mass PBH we have mentioned, $10^{14} M_\odot$, this means that the decay lifetime satisfies $\tau_{PBH} \lesssim 10^{115}$ yr. We note that this lifetime is not only much longer than the age a_U of the universe, $a_U \sim 1.38 \times 10^{10}$ yr but also much longer than the maximum estimate [6] for the proton decay lifetime τ_p which is $\tau_p \lesssim 10^{50}$ yr.

The most massive known SMBH at a galactic core is in NGC4889, 336 Mly away, with mass $2.1 \times 10^{10} M_\odot$. A heavier one, the most massive known black hole, is in quasar S5 0014+81, 12.1Gly away, with mass $4 \times 10^{10} M_\odot \sim 10^{10.6} M_\odot$. We have adopted $10^{14} M_\odot$ as a speculation for the most massive PBH in the visible universe, only as about the geometric mean of the most massive possible PBH and the most massive known BH. This precise value is not important to our discussion, as from Eq.(1) we see that any PBH above $10^{12} M_\odot$ has an evaporation lifetime over one googol years.

Such an extraordinarily long lifetime for the PBH decay might, at first, seem unique within the context of the minimal standard model and general relativity. But our purpose in the note is to emphasize that there is not only one but actually two [7] other lifetimes in excess of 10^{100} yr which are not dissimilar from, and consistent with, τ_{PBH} .

2.2 Instantons

Although perturbatively the standard model conserves baryon number and hence the proton is stable, this ceases to be true when instantons are taken into account. At zero temperature, the instanton effects are exponentially

suppressed and an estimate of the proton lifetime $\tau_{p,inst}$ for instanton-induced decay [8,9] is much much longer than the value of τ_p cite above, and is given by

$$\tau_{p,inst} \simeq \exp(+4\pi\sin^2\Theta_W/\alpha_{em}) \quad (2)$$

This estimate, Eq.(2), has a numerically-irrelevant prefactor and gives an instanton-induced proton decay lifetime with a lower limit of at least $\tau_{p,inst} > 10^{100}$ y.

This is not a prediction which can be directly tested since it is empirically indistinguishable from absolute stability, and therefore seems, *prima facie*, academic. Nevertheless, this lifetime $\tau_{p,inst}$ is consistent with τ_{PBH} .

2.3 Vacuum Metastability

In 2012 the Higgs boson was discovered with a mass of $M_H \simeq 126$ GeV and using the best measured value for the top quark mass M_t an analysis [10] of the effective potential of the minimal standard model with only one complex scalar doublet revealed that the physical vacuum in which we live is metastable with an exceptionally long lifetime.

This metastability is sensitively dependent on M_H and M_t and only a small variation from the measured values of these two quantities would provide absolute stability. As examples if we fix M_H at its physical value and reduce the top mass to 171 GeV from the correct value ~ 173.36 GeV, or if we fix M_t at its correct value and increase M_H to 130 GeV from its physical value ~ 125.66 GeV, the vacuum would be stable.

The interpretation of this phenomenon remains unclear, and with the physical M_H and M_t additional states can render the vacuum stable as illustrated in [11].

If we retain only the minimal number of states in the standard model the vacuum lifetime is a similarly exceptional time of $\tau_{vac} \sim 10^{100}$ yr.

3 Discussion

Two of the three lifetimes we have mentioned were put equal in [7], $\tau_{p,inst} = \tau_{vac}$ with, as only variable, the Higgs mass M_H . This led to the result

$M_H = 126 \pm 4$ GeV and could be regarded as a prediction for the otherwise unexplained Higgs mass. Putting the two lifetimes equal does not yet have another justification.

A similar argument could be used for τ_{PBH} for the supermassive PBHs in the universe to argue about the value of the highest mass black hole in the universe, although again the assumption that the maximum τ_{PBH} is equal to one of the other two lifetimes τ_{vac} or $\tau_{p,inst}$ is necessary.

It is our belief that the two “cosmic” coincidences between the three exceptional lifetimes might have a deep significance for theoretical physics and may play a role in a more complete theory.

Acknowledgement

This work was initiated at the MIAMI2016 Conference held in Fort Lauderdale in December 2016 and organized by T.L. Curtright of the University of Miami.

References

- [1] P.H. Frampton, *Searching for Dark Matter Constituents with Many Times the Solar Mass*.
Mod. Phys. Lett. **A31**, 1650093 (2016). [arXiv:1510.00600 \[hep-ph\]](#).
- [2] G.F. Chapline and P.H. Frampton, *Intermediate Mass MACHOs: A New Direction for Dark Matter Searches*.
JCAP **11**, 042 (2016). [arXiv:1608.8713 \[hep-ph\]](#)
- [3] P.H. Frampton, *The Primordial Black Hole Mass Range*.
Mod. Phys. Lett. **A31**, 1650064 (2016). [arXiv:1511.08801 \[gr-qc\]](#)
- [4] P.H. Frampton, M. Kawasaki, F. Takahashi and T.T. Yanagida, *Primordial Black Holes as All Dark Matter*.
JCAP **1004**, 023 (2010). [arXiv:10011.2308 \[hep-ph\]](#)
- [5] B.J. Carr, K. Kohr, Y. Sendouda and J. Yokoyama, *New Cosmological Constraints on Primordial Black Holes*.
Phys. Rev. **D81**, 104019 (2010). [arXiv:0912.5297 \[astro-ph.CO\]](#).
- [6] A.D. Sakharov, *Violation of CP Invariance, C Asymmetry and Baryon Asymmetry of the Universe*.
Pisma Zh. Eksp. Teor. Fiz. **5**, 32 (1967); JETP Lett. **5**, 24 (1967).

- [7] P.H. Frampton and P.Q. Hung, *A Possible Reason For $M_H \simeq 126$ GeV*. Mod. Phys. Lett. **A29**, 1450006 (2014). [arXiv:1310.3904 \[hep-ph\]](#).
- [8] G. 't Hooft, *Symmetry Breaking Through Bell-Jackiw Anomalies*. Phys. Rev. Lett. **37**, 8 (1976).
- [9] G. 't Hooft, *Computation of the Quantum Effects Due to a Four Dimensional Pseudoparticle*. Phys. Rev. **D14**, 3432 (1976).
- [10] D. Buttazzo, G. Degrassi, P.P. Giardino, G.F. Giudice, F. Sala, A. Salvio and A. Strumia. *Investigating the Near-Criticality of the Higgs Boson*. JHEP **1312**, 089 (2013). [arXiv:1307.3536 \[hep-ph\]](#)
- [11] L.V. Laperashvili, H.B. Nielsen and C.R. Das, *New results at LHC confirming the vacuum stability and Multiple Point Principle*. Int. J. Mod. Phys. **A31**, 1650029 (2016) [arXiv:1601.03231 \[hep-ph\]](#).